ULTRASONIC ABSORPTION IN NORMAL AIR AT 456 Kc/s FOR DIFFERENT HUMIDITIES

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Plate XII

ABSTRACT. A simpler treatment of the ultrasonic absorption formula

$$\mu = \frac{2.303\,[\log_{10}\Delta\theta_A - \log_{10}\Delta\theta_B]}{n_B - n_A}$$

is presented here A stable and sensitive Pierce interferometer has been used to measure ultrasonic absorption in normal air at 455.8 Kc/s for different humidities. The special features of the work are the use of a proper crystal mounting and the use of a large volume humidity cabinet in which the interferometer was placed. It is found that the absorption curve shows a peak at about 48% humidity for the frequency used in the work.

INTRODUCTION

It is now well established that absorption of ultrasonic energy in fluids is not only the result of viscous and conductivity losses but some sort of relaxation phenomenon is responsible for it. Three types of relaxation effects have been suggested: firstly the lag in sharing of energy by vibrational states, secondly the lag in chemical or quasi-chemical changes and lastly configurational relaxation. In the case of gases, in which we are concerned here, vibrational relaxation has been found widely evident. The absorption due to this effect is explained qualitatively as follows: As pressure waves pass through a gas, there occurs a sinusoidal variation in temperature along its path. The molecules get energised and transfer a part of their translational and rotational energy to inner vibrational states during compression and take it back while rarefaction occurs, or say a number of molecules are excited to higher vibrational energy levels and then brought back to normal state. But the inner states do not follow readily in taking the energy or giving it back and consequently there is always a phase lag between ultrasonic pressures and corresponding volume changes. Such a lag leads to a closed PV curve implying thermodynamically that fluid has done some work, absorbing energy from the ultrasonic waves. The amplitude of the lag can be varied either by changing the acoustical period or the relaxation period. The relaxation period depends upon the collision rate and the efficiency of collision to bring about transition. The efficiency function varies with the nature of the colliding molecules which is a fact of importance in the case of mixture of gases.

Our present case is a mixture of nitrogen, oxygen and carbon dioxide in normal air proportions with varying water content.

INTERFEROMETER THEORY:

The determination of absorption of the ultrasonic energy in fluids is done by the method of ultrasonic interferometry. The method was put in use as early as 1925 by Pierce (1925) which has been later improved by several workers to an extent that its accuracy is quite at par with its optical analogue. It is a standing wave method where the source of ultrasonic waves is an oscillating piezo-electric plate set into vibrations by usual vacuum tube oscillators, and the reflector is either of metal or glass. The ultrasonic waves after multiple reflections react cumulatively on the crystal source which also acts as the detector of the standing waves. Due to reaction pressure electrical constants of the crystal change, which gives rise to variations in crystal voltage and the current in its circuit. The reaction will be a function of the density of the fluid, velocity of the waves and the attenuation of the energy in the medium. Hence knowing the variations in the circuit current or voltage and the relevent relation, attenuation can be calculated. Calculations have been made by Hubbard, (1931) Herzfeld (1938) and Alleman (1939). A simpler treatment is given below :

Assuming plane waves we write down the particle velocity $\dot{\xi}$ of attenuated waves as

$$\dot{\xi}_i = A \exp\left[(j\omega - k)\left(t - \frac{x}{v} \right) \right] \qquad (1)$$

where ω, k and v are angular frequency, attenuation constant and velocity of sound waves respectively in the fluid. The origin of x-axis is the surface of the quartz crystal.

The particle velocity of the reflected waves will be given by the expression

$$\dot{\xi}_r = B \exp\left[(j\omega - k)\left(t + \frac{x}{v} \right) \right] \qquad \ldots \quad (2)$$

where A and B are complex velocity amplitudes of the waves. The resulting particle velocity at any point x will be

$$\dot{\xi} = \exp(j\omega - k)t \left[A e^{-(j\omega - k)x/v} + B e^{-(j\omega - k)x/v} \right] \qquad \ldots \quad (3)$$

Since the particle velocity on the surface of the reflector is zero, we find that at $x = l$, where l is the distance of the reflector from the source,

$$A e^{-(j\omega - k)l/v} = -B e^{(j\omega - k)l/v} = \frac{C}{2} \text{ (say)} \qquad \ldots \quad (4)$$

Substituting for A and B from (4) in (3), we get

$$\dot{\xi} = C \exp(j\omega - k)\, t \, \sinh (j\omega - k)\left(\frac{l - x}{v} \right) \qquad \ldots \quad (5)$$

Since the pressure is given by

$$p = -\frac{v^2\rho}{(j\omega - k)}\frac{d\dot{\xi}}{dx} \qquad \ldots \quad (6)$$

we find at $x = 0$

$$\frac{p}{\dot{\xi}_0} = v\rho \coth (jw - k)\frac{l}{v} \qquad \ldots \quad (7)$$

where $\dot{\xi}_0$ represents the particle velocity at the crystal surface. Equation (7) can be expanded in the form

$$p = v\rho\dot{\xi}_0 \frac{\sinh \frac{2kl}{v} + i \sin \frac{2\omega l}{v}}{\cosh \frac{2kl}{v} - \cos \frac{2\omega l}{v}} \qquad \ldots \quad (7a)$$

Equation (7a) shows that as the length l is altered, the pressure will pass through maximum and minimum values. When $l = r\lambda/2$ the pressure will be

$$p_{max} = v\rho\dot{\xi}_0 \frac{\sinh 2kl/v}{\cosh 2kl/v - 1} \qquad \ldots \quad (8)$$

and when

$$l = \left(r + \frac{1}{2}\right)\frac{\lambda}{2} = l' \text{ (say)}$$

$$p_{min} = v\rho\dot{\xi}_0 \frac{\sinh 2kl'/v}{\cosh 2kl'/v + 1} \qquad \ldots \quad (9)$$

Since $l' \simeq l$; [$\lambda/4$ too small as compared to l]

$$p_{min} = v\rho\dot{\xi}_0 \frac{\sinh 2kl/v}{\cosh 2kl/v + 1} \qquad \ldots \quad (9')$$

Thus pressure difference

$$(p_{max} - p_{min}) = \Delta p = \frac{2v\rho\dot{\xi}_0}{\sinh 2kl/v} \qquad \ldots \quad (10)$$

At any position A of the reflector at a distance l_A from the source the pressure difference is

$$\Delta p_A = \frac{2v\rho\dot{\xi}_{0A}}{\sinh 2kl_A/v} \qquad \ldots \quad [11]$$

Similarly for the position B

$$\Delta p_B = \frac{2v\rho\dot{\xi}_{0B}}{\sinh 2kl_B/v} \qquad \ldots \quad [12]$$

Taking $\dot{\xi}_{0A} \simeq \dot{\xi}_{0B}$ we get

$$\frac{\Delta p_A}{\Delta p_B} = \frac{\sinh 2kl_B/v}{\sinh 2kl_A/v} \qquad [13]$$

It can be shown for the Pierce oscillator, treating on similar lines as that followed by Hardy, (1943) that

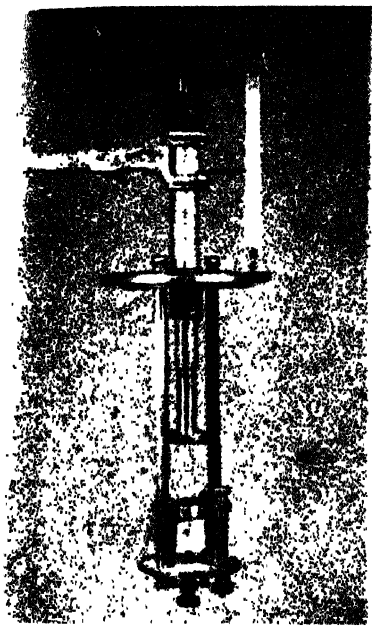


Fig 1.
The interferometer

Fig. 2
The crystal holder

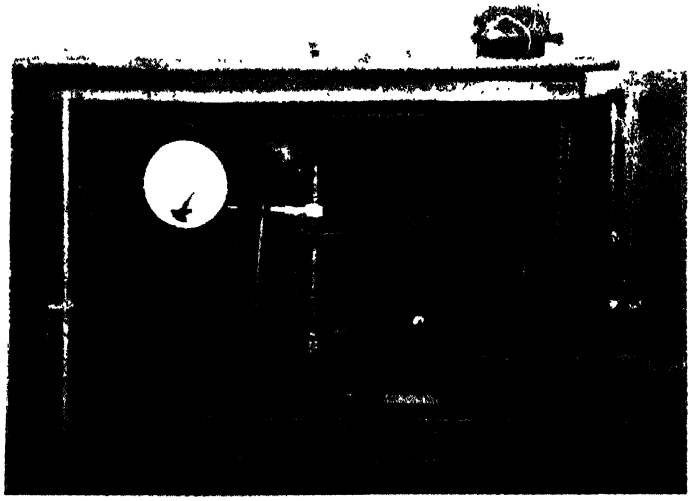


Fig 3

The humidity chamber

$$\frac{\Delta p_A}{\Delta p_B} = \frac{\Delta E_A}{\Delta E} = \frac{\Delta I_A}{\Delta I_B} = \frac{\sinh 2kl_B/v}{\sinh 2kl_A/v} \quad \ldots \quad [14]$$

where ΔE_A and ΔE_B are crystal voltages corresponding to Δp_A and Δp_B and ΔI_A, ΔI_B are corresponding changes in the plate current. Putting $k/v = \alpha$ and assuming either α or l to be large we get,

$$\frac{\Delta I_A}{\Delta I_B} = \frac{\Delta \theta_A}{\Delta \theta_B} = e^{2\alpha(l_B - l_A)} = e^{\mu(n_B - n_A)}$$

($\Delta\theta_A$ and $\Delta\theta_B$ are the deflections observed in a sensitive galvanometer placed in the plate circuit).

$$= \frac{2.303[\log_{10}\Delta\theta_A - \log_{10}\Delta\theta_B]}{(n_B - n_A)} \quad \ldots \quad [15]$$

where μ is the 'coefficient of energy absorption per wavelength' and $(n_B - n_A)$ is the number of full wavelengths between the two positions of the reflector A and B.

EQUIPMENT

Our interferometer (figure 1) is of the usual type having a quartz plate as a source of ultrasonic waves and well-polished brass reflector moved by a precision micrometer screw. The arrangement for the movement of the reflector is so managed that there is no rotation of the reflector plane when it is moved along its axis and if it is once carefully made parallel it remains so throughout its movement.

The crystal mounting is of great importance in the interferometric work as a faulty setting will create distortion in crystal oscillations and the changes in the plate current will be unreliable. Distortion in wave form occurs if the crystal is placed on a plate electrode because it knocks against it while oscillating. Thus a rigid mounting, yet free in longitudinal direction, is required. The crystal in our interferometer has been fixed in its median nodal plane by four screws and electrical contacts have been made by light springs (figure 2) after silvering the crystal surfaces thinly. Although our crystal was not a 71° cut, yet it is hoped that this kind of mounting gives more or less a piston like motion of the crystal thus producing plane waves.

The interferometer was placed in a humidity chamber (figure 3). The reflector is moved by a knob attached to a graduated disc kept outside the chamber. The rod connecting the knob and the reflector is passed through a well-greased air-tight hole in the chamber roof. The double doors of the chamber have thick paddings on their sides to make them air-tight. The whole chamber is covered inside by thick copper sheets and outside by asbestos sheets to avoid temperature variation inside the chamber. Electrical heaters, with automatic electric temperature control, are provided to dry the chamber. To increase humidity a water tank and a pipe surrounded by a heater coil with regulator for its controlled evaporation are fitted. A fan for the suction of water vapour inside the chamber is also provided. To

obtain uniform humidity throughout the chamber, it is allowed to stabilise itself by leaving the chamber to stand for a few hours with a particular water content. Humidity is measured by a calibrated hair hygrometer.

As regards the excitation of the quartz plate Pierce oscillator, using a low power triode (Philips A 410), has been employed for stable vibrations. Dry batteries have been used for high tension to avoid spurious fluctuations due to power supply.

Frequency of the oscillations has been measured by a standard Signal Corps frequency meter (Type No. BC 221 AH) which comes out to be 455.8 Kc/s.

OBSERVATIONS

Observations have been taken at room temperature (32°C) at a frequency of 455.8 Kc/s at five different humidities ranging from 30% to 70% in normal air. A representative set of variations of plate current with respect to reflector positions is shown in figure 4. The plate current undergoes quite

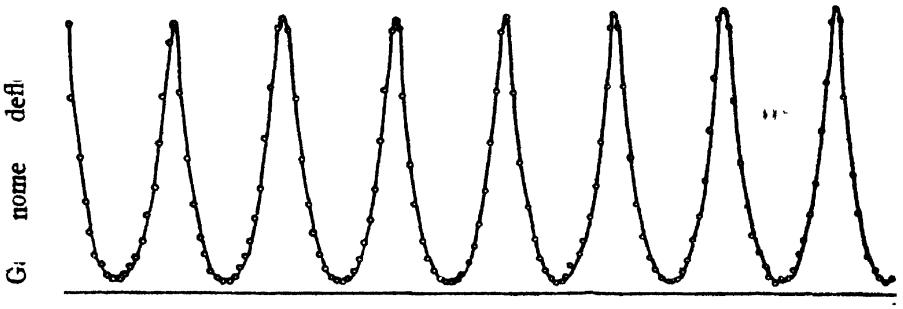
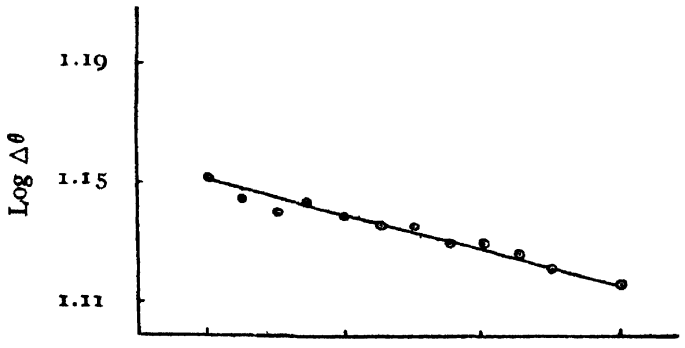


FIG. 4



n—Number of resonant positions
Humidity = 31% $\mu = .01266$

FIG. 5

smooth and regular changes which shows that source is giving out fairly plane waves and the reflector remains parallel to the source. Figures 5 and 6 are two representative graphs of log $\Delta\theta$ against number of resonant positions. The mean straight curve is drawn through the points and μ is calculated from the slope of the straight line.

RESULTS

Absorption values have been calculated from the slope of the curves given above. Table I shown underneath gives the absorption values at different humidities :

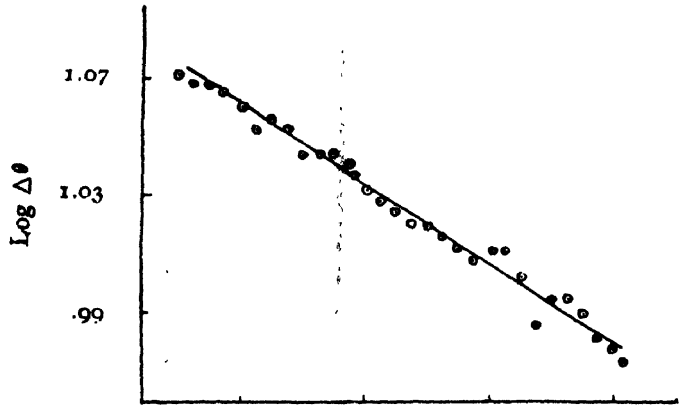


FIG. 6

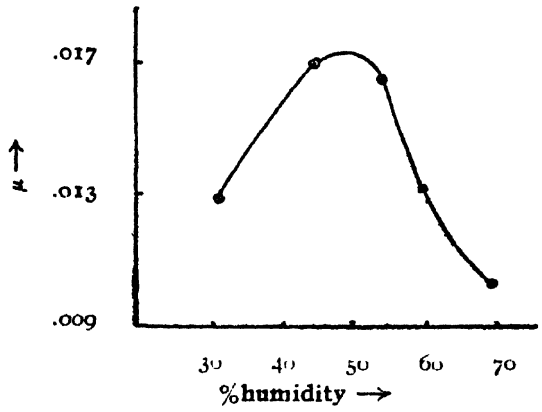


FIG. 7

Table I

Relative humidity ...	31%	44·5%	54%	59 5%	70%
Absorption (μ) ...	.01266	.01675	.01634	.01289	.00998

Coefficient of absorption per wave length, μ, is plotted against percentage humidity shown in figure 7. The curve is similar to that for carbon-dioxide (Pielmier, *et al*, 1940) and shows a peak near 48% of humidity.

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